# SEISMIC ANALYSIS OF OVERHEAD CIRCULAR WATER TANKS – A COMPARITIVE STUDY

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## Abstract

*This paper compares the results of seismic analysis of overhead circular water tank carried out in accordance with IS: 1893-1984 and IS: 1893-2002 (Part-2) draft code. The analysis is carried out for elevated circular tank of 1000 Cu.m capacity, located in four seismic zones (Zone-II, Zone -III, Zone-IV, Zone-V) and on three different soil types (Hard rock, Medium soil, Soft soil). Further, three different tank-fill conditions - tank full, tank 50% full, tank empty are also considered in this study. The seismic responses of circular tanks are computed and compared based on the theoretical procedures of IS: 1893-1984 and IS: 1893-2002(Part-2) draft code. The analysis was performed using SAP-2000 software package also. The parameters of comparison include base shears, base moments, impulsive and convective hydrodynamic pressures on tank wall and base slab. The results of the analysis showed an increase in base shear, base moment, hydrodynamic pressure and time period with increasing zone factor for all soil types and tank fill conditions considered. The increase in base shear and base moment are found to be in the range of 54% -260% in the analysis performed using draft code over the values of IS: 1893-1984. The hydrodynamic pressure increased in the range of 54%-280% with the use of draft code over the values obtained based on IS: 1893-1984. The results of SAP-2000 are found to be in agreement with those of the draft code.*

***Keywords** – Base shear; Base moment; Hydrodynamic pressure; Draft code; Time period; and SAP-2000.*

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## 1. INTRODUCTION

Water supply is a life-line facility that must remain functional even after the strike of an earthquake. Water supply system depends on overhead tanks for storage in our country. These tank structures have a configuration vulnerable to the action of horizontal forces like earthquakes owing to large total mass concentrated at the top of a slender supporting structure. Therefore, the design of R.C liquid storage tanks against earthquake effects assumes significance in view of potentially disastrous results associated with liquid storage tank failures. Past experiences revealed that elevated water tanks were heavily damaged or collapsed during earthquakes and this might be due to the lack of knowledge about the proper behaviour of supporting system of the tank against dynamic effect and also due to improper geometrical selection of staging patterns. Further, there have been a few instances of failure of tanks and reservoirs occurred not because of shortcomings of specifications but due to other reasons that surfaced from the failures of water tanks. For instance, failure of tanks during Chilean earthquake of 1960 and Alaska earthquake of 1964 gave way for investigations on seismic analysis of liquid storage tanks and brought two aspects such as, i) due consideration to sloshing effects of liquid and flexibility of container wall in evaluating seismic forces on tanks and ii) less ductility and low energy absorbing capacity and redundancy of water tanks in comparison to conventional building systems, into lime light. Indian subcontinent is highly vulnerable to natural disasters like earthquakes, floods, cyclones etc., and according to IS: 1893-2002 (Part-1) more than 60% of India is prone to earthquakes. The main reason for life loss during earthquakes is the collapse of structures that aren't designed to resist the earthquakes of intensity that struck the region. Since the elevated tanks are frequently used in seismically active regions also, their seismic behaviour of has to be investigated in detail.

## 2. LITERATURE REVIEW

Significant research was carried out on a seismic design of liquid storage tanks and a few published works on seismic response characteristics of reinforced concrete (RC) water tanks are reviewed in this section. Jain and Sajjad [11] reviewed the I.S. code provisions for seismic design of elevated water tanks, based on seismic codes of other countries and reports of several investigations and made a valid observation that the seismic design force in IS 1893-1984 is rather low owing to the absence of suitable performance factor that must be in the range of 3.0-4.5. Jaiswal and Jain [9,10] proposed major modifications in respect of seismic design of liquid storage tanks, recognizing the limitations in the provisions of IS: 1893-1984 and provided commentary & examples on the modified provisions. Vamsidhar [13] analyzed sixteen different types of tanks using IS: 1893-1984 and the proposed specification IS: 1893-2002 (part-2) draft code. It has been observed that there is an increase of 15% to 25% in hydrodynamic forces over hydrostatic forces and 50% increase of base shear in zone- IV as compared to the current specifications. Hirde et. al [3] studied the seismic performance of elevated water tanks of various heights & capacities under varying zones & soil types of India. It was concluded that earthquake forces decrease with increase in staging height for the reason that with increasing staging height the structure becomes more flexible. Gaikwad [1] reviewed the behaviour of elevated water tank by performing static and dynamic analysis, to compare the analysis results of elevated water tank, in order to study the effect of hydrodynamic forces on elevated water tank. Gaikwad[2] studied the behaviour of elevated water tank with framed staging when subjected to lateral earthquake load using IITK-GSDMA Guidelines. Ekbote [12] conducted a study to know the behaviour of supporting system. Different supporting systems such as radial bracing and cross bracing have been used and compared. The reasons for failure of elevated tanks were reviewed and realized that improper behavior of supporting system and improper geometrical selection of staging patterns are the main causes.

## 3. METHODOLOGY

The methodology includes the selection of type of water tank, fixing the dimensions of components for the selected water tank and performing linear dynamic analysis (Response Spectrum Method of Analysis) by IS: 1893-1984 and IS: 1893-2002 (Part 2) draft code. In this study, a 1000 Cu.m capacity circular overhead water tank is considered for analysis. It is analysed for four different zones (zone-II to V), three soil types, i.e. hard rock, medium soil, soft soil and for three tank-fill conditions, i.e. tank full, tank 50% full and tank empty conditions. Lastly, the results of the analysis of circular tank performed on the basis of IS: 1893-1984 and IS: 1893-2002 (Part 2) draft code have been compared. The analysis was also carried out using the software SAP-2000.

### 3.1 Analysis Using Response Spectrum Method

In response spectrum method, the response of a structure during an earthquake is obtained directly from the earthquake response (or design) spectrum. This method gives an approximate peak response, which is quite accurate for structural design applications. Time period of structure is determined on the basis of the lateral stiffness of structure. From the time period, the responses of structure is determined using modal combination methods such as complete quadratic combination (CQC), square root of sum of squares (SRSS), or absolute sum (ABS) method. Response spectrum method of analysis is performed using the design spectrum specified or by a site – specific design spectrum, which is specifically prepared for a structure at a particular project site. The procedure to compute seismic responses using IS: 1893-1984 is from clause 3.4.2.3. Time period of structure and hydrodynamic pressures are calculated from clause 5.0 elevated tanks. The procedure for determination of seismic response is as follows.

### 3.2 Procedure for calculation of Seismic Responses Using IS: 1893-2002(Part 2) Draft Code.

**Step-1**: Based on capacity of water tank, fix the approximate dimensions for each component of water tank.
**Step-2:** Compute the seismic weight of the water tank with staging (W).
**Step-3:** Determine the c.g of empty container from top of footing.
**Step-4:** Find the parameters of spring mass model based on h/D ratio of water tank. i.e. ($m_i$, $m_c$, $h_i$, $h_i$*, $h_c$, $h_c$*).
**Step-5:** Compute the lateral stiffness of staging. [Clause 4.3.1.3 of IS: 1893-2002(Part-2) draft code]
**Step-6:** Compute the impulsive and convective time period for water tank.

$T_i=2\pi\sqrt{}\,(m_i+m_s)/k_s$ [Clause 4.3.1.3 & 4.3.2.2(a) of IS: 1893 - 2002(Part-2) draft code]

**Step-7:** Compute design horizontal seismic coefficient for impulsive & convective mode.

$(A_h)_i$=ZI (Sa/g)/ (2R) [Clause 4.5 & 4.5.1 of IS: 1893-2002 (Part-2) draft code]

$(A_h)_i$ = Design horizontal acceleration spectrum value
Z= Zone factor in Table 2 of IS: 1893-2002(Part-1),
I= Importance factor given in Table 1 of IS: 1893-2002(Part-2) draft code,
R=Response reduction factor given in Table 2 of IS: 1893-2002(Part-2) draft code,

$S_a/g$= Average response acceleration coefficient as given by Fig.2 and Table 3 of IS: 1893-2002(Part -1) [Clause 4.5.1 & 4.5.4 of IS: 1893-2002 (Part-2) draft code]

**Step-8**: Compute base shear (V) at the bottom of staging for elevated water tank in impulsive & convective mode $V_i=(A_h)_i(m_i+m_s)g$, $V_c=(A_h)_c(m_i+m_s)g$ & $V=\sqrt{}(V_i^2)+(V_c^2)$
**Step-9:** Compute base moment in impulsive and convective mode (M*).

$$M^*=\sqrt{}\,(M_i^*) + (Mc^*)$$

**Step-10:** Finally compute, hydrodynamic pressure on wall ($P_w$) and base slab ($P_b$) in impulsive & convective mode.

$P_{iw}=Q_{iw}(y)\,(A_h)_i\rho gh\cos\varphi$,

$Q_{iw}=0.866\,[1-(y/h)^2]\tanh(0.866(D/h))$ [Clause 4.9.1(a) of IS: 1893-2002(Part-2) draft code]

$Pib=0.866(Ah)i\rho gh\,Sinh(0.866x/h)/Cosh(0.866D/h)$

$Pcw=Qcw(y)(Ah)c\rho ghD(1-1/3\cos^2\Phi)\cos\Phi$,
$Q_{cw}(y)=0.5625\cosh(3.674*y/D)/\cosh(3.674*h/D)$ [Clause 4.9.2(a) of IS:1893-2002(Part-2) draft code]

$Pcb=Qcb(x)(Ah)c\rho gD$,
$Qcb(x)=1.125((x/D)-(4/3)(x/D)3)sech(3.674*h/D)$

## 4. ANALYSIS OF CIRCULAR OVERHEAD WATER TANK

The details of the 1000 Cu.m circular overhead water tank considered for the seismic analysis are as mentioned below:

### 4.1 Structural Details

- Structure = OMRF
- Height of each bracing level= 3.6 m
- Depth of foundation below plinth beam = 2.7 m
- Height of column = 13.5 m
- Wall Thickness = 300 mm
- Materials = Fe 415 & M25
- Zone = II to V
- Size of column = 600 mm dia
- Sizes of beams in transverse and longitudinal direction = 400 mm x 600 mm
- Tie beams = 300 mm x 500mm
- Thickness of floor slab = 300 mm
- Thickness of roof slab = 120 mm

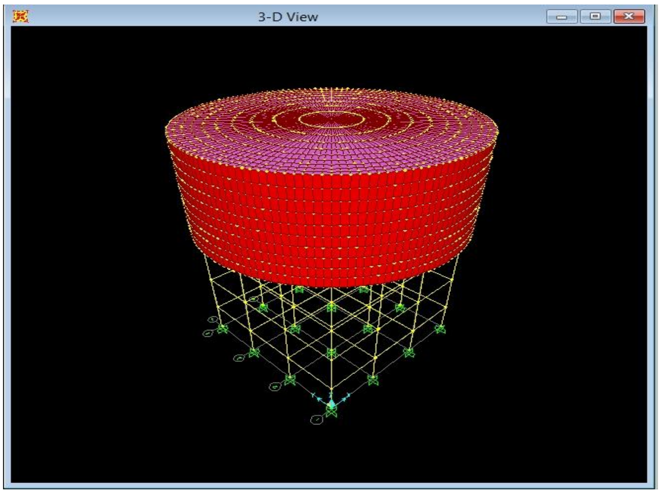


**Fig. 1** 1000cu.m Overhead Circular Tank modeled in SAP 2000

A 1000 cum circular over head water tank modeled using SAP-2000 is shown in fig.1. Analysis was carried out using IS: 1893-1984, IS: 1893-2002 (Part 2) draft code and SAP-2000 software package.

## 5. RESULTS AND DISCUSSIONS

### 5.1 Presentation of Test Results

The Results of analysis, in terms of base shear, base moment, and hydrodynamic pressure on wall and base of water tank, in Seismic zones II to V and for various soil types are presented in figs. 2 to 15.

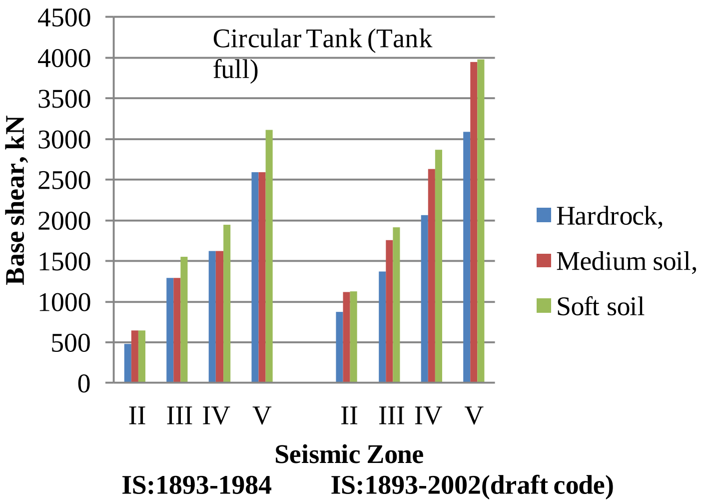


**Fig 2:** Base shear Vs Seismic Zone (Tank Full)

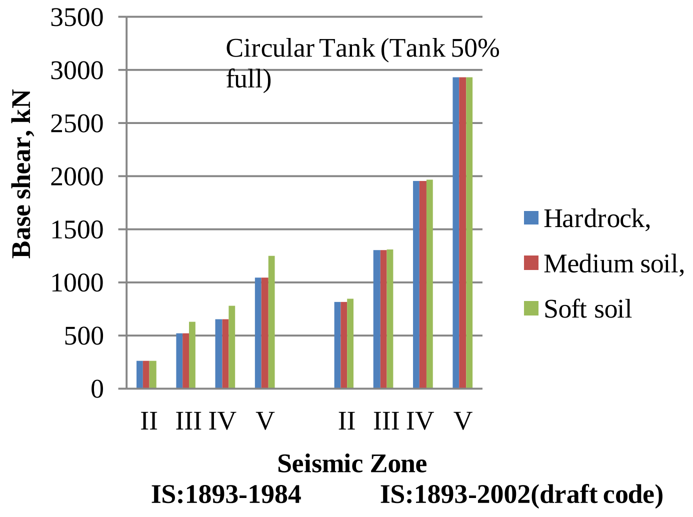


**Fig3:** Base shear Vs Seismic Zone (Tank 50% full)

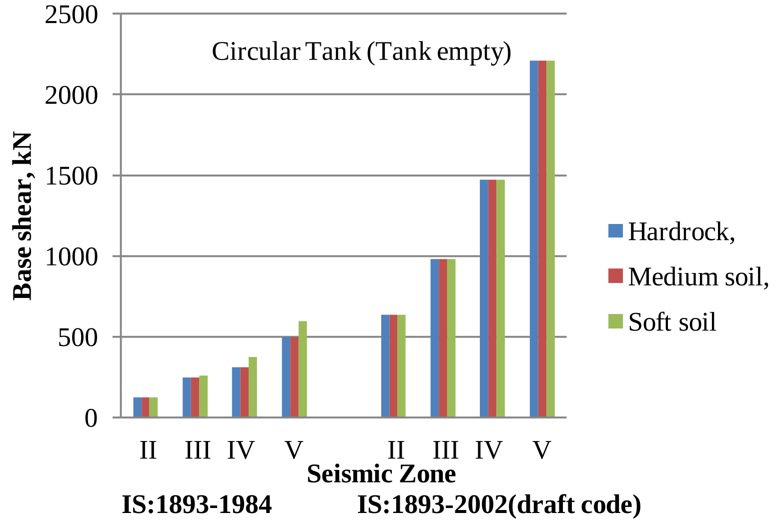


**Fig 4:** Base shear Vs Seismic Zone (Tank Empty)

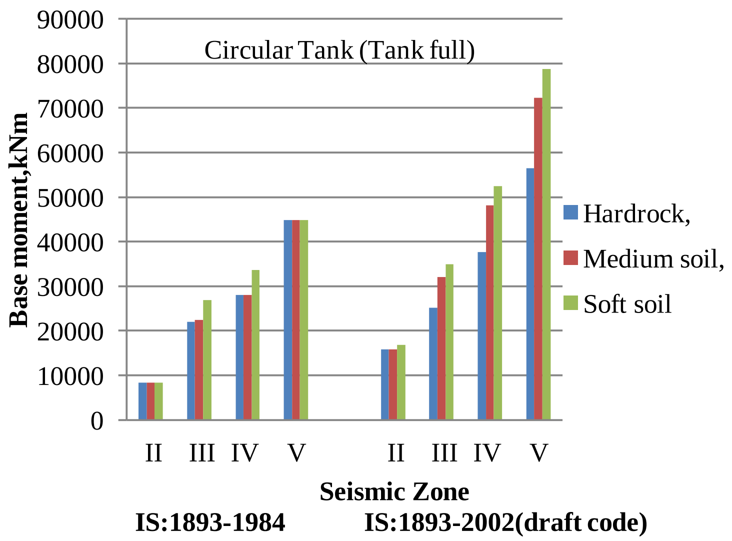


**Fig 5:** Base moment Vs Seismic Zone (Tank Full)

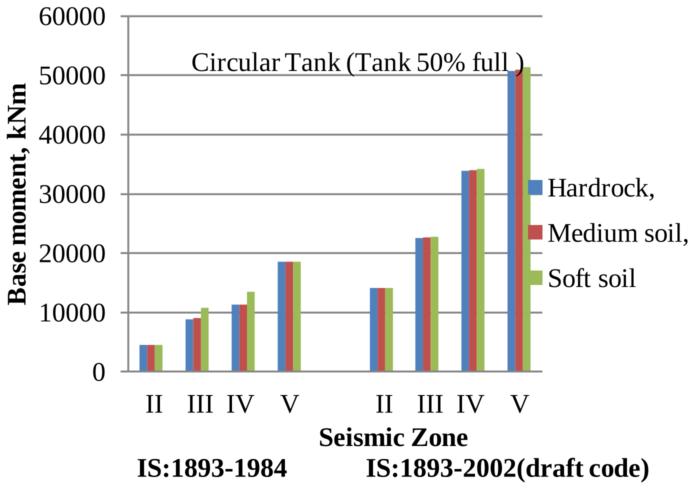


**Fig 6:** Base moment Vs Seismic Zone (Tank 50% full)

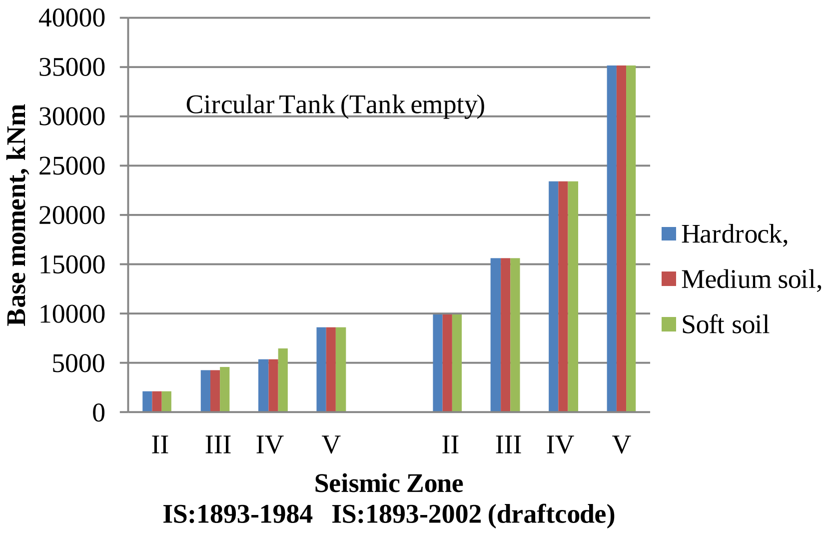


**Fig 7:** Base moment Vs Seismic Zone (Tank Empty)

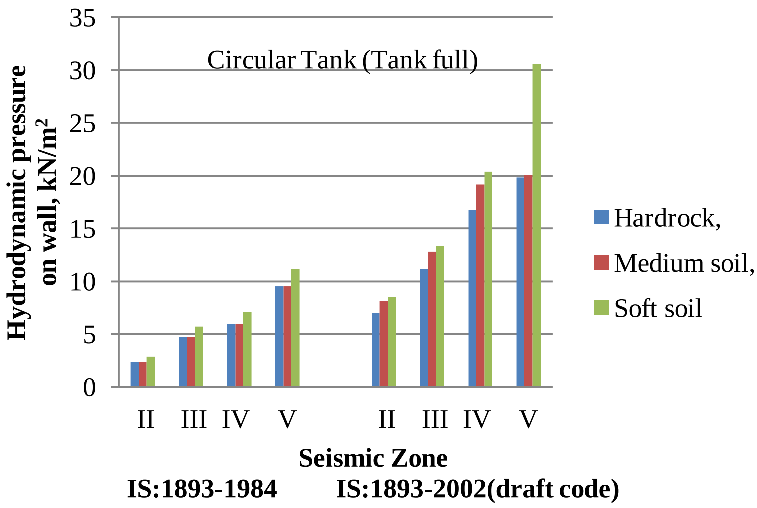


**Fig. 8** Hydrodynamic pressure on wall Vs Seismic Zone (Tank Full)

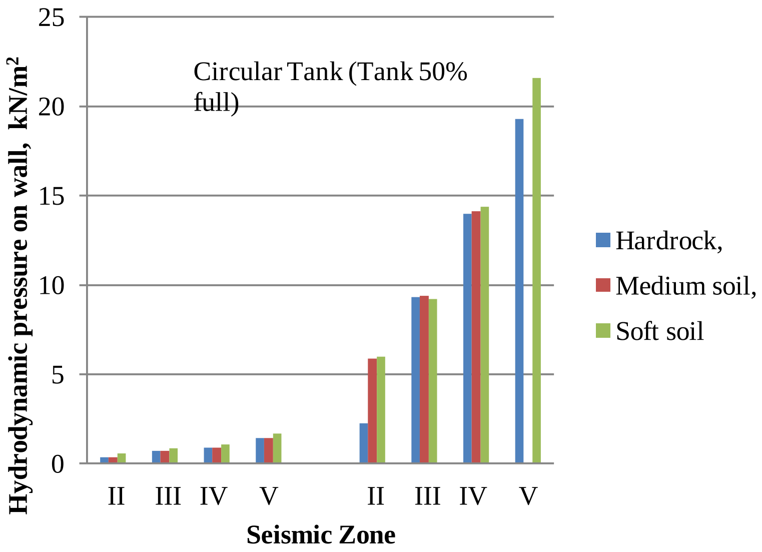


**Fig. 9** Hydrodynamic pressure on wall Vs Seismic Zone (Tank 50% full)

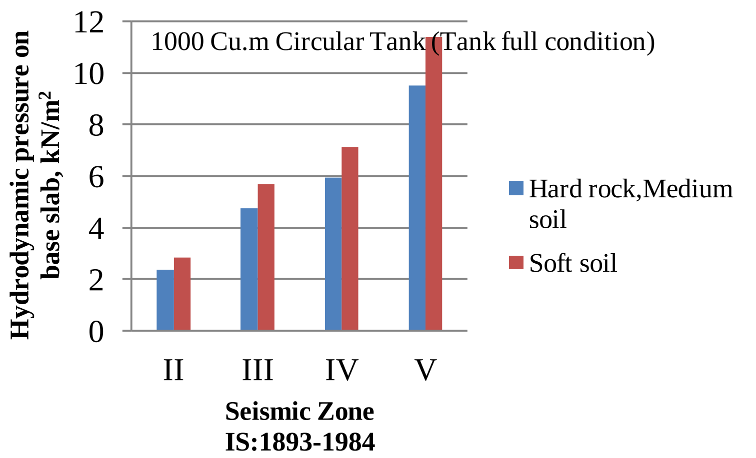


**Fig 10:** Hydrodynamic pressure on Base slab Vs Seismic Zone (Tank Full)

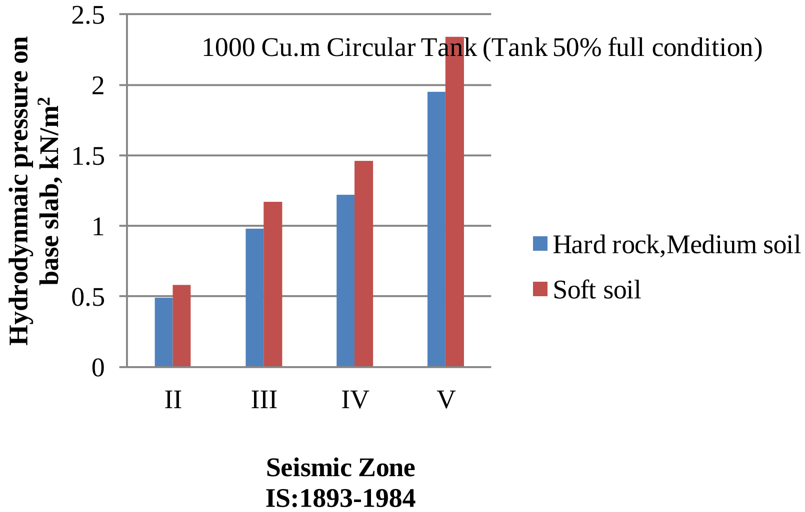


**Fig 11:** Hydrodynamic pressure on Base slab Vs Seismic Zone (Tank 50% full)

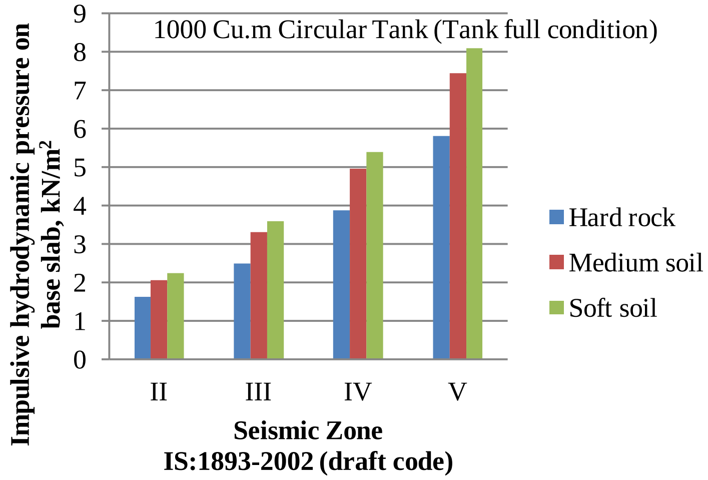


**Fig. 12** Impulsive Hydrodynamic pressure on Base slab Vs Seismic Zone (Tank Full)

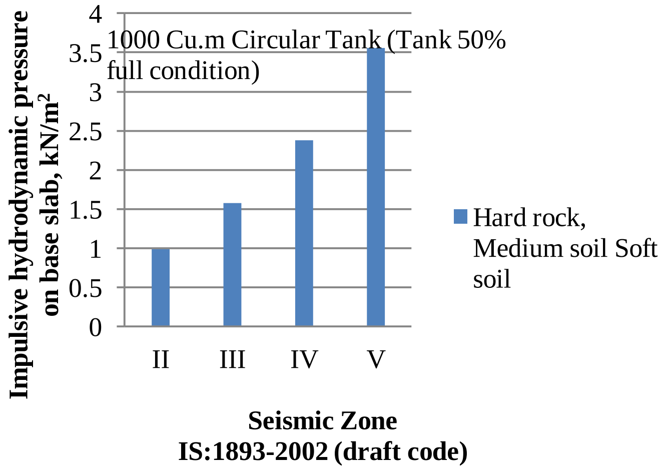


**Fig. 13** Impulsive Hydrodynamic pressure on base slab Vs Seismic Zone (Tank 50% full)

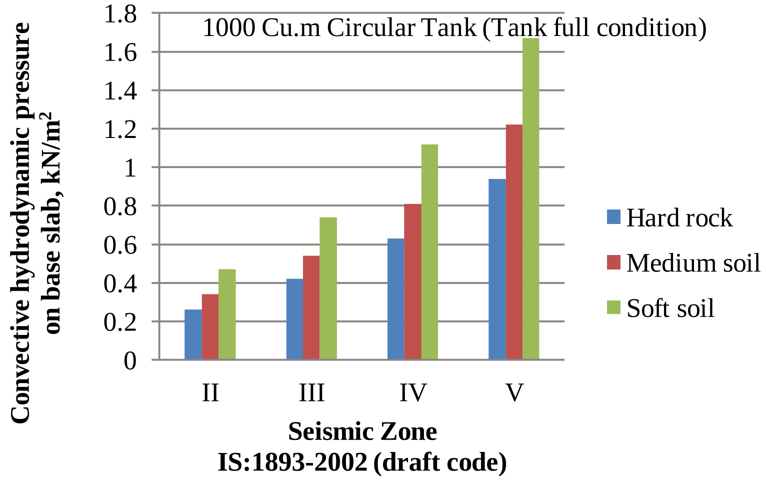


**Fig. 14** Convective Hydrodynamic pressure on Base slab Vs Seismic Zone (Tank Full)

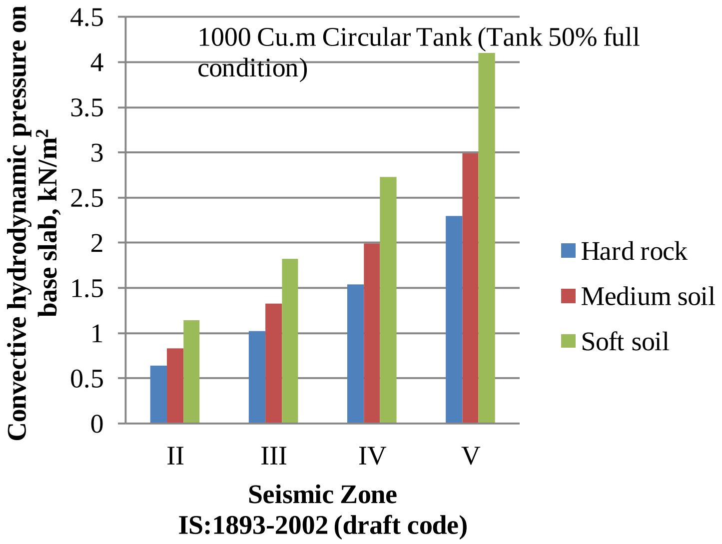


**Fig. 15** Convective Hydrodynamic pressure on base slab Vs Seismic Zone (Tank 50% full)

## 5.2 Discussions

### 5.2.1 Effect of Seismic Zone on Base Shear

Figs. (2 - 4) depict the variation of base shear with seismic zone i.e. Zone factor and it could be observed that the base shear increased with increasing zone factor, which increases from zone II to V, for all types of soils (hard rock, medium soil and soft soil) and also for different tank-fill conditions i.e. tank full condition, tank 50% full condition and tank empty condition. In the analysis of 1000 Cu.m overhead circular tank, as per IS:1893-1984 Provisions, base shear increased by 100%, 150% and 300% as the zone changed from II to III, IV and V respectively in case of hard rock. The corresponding values are found to be 100%, 150% & 300% and 100%, 108% & 147% respectively in medium and soft soil for tank full condition. On the other hand, the values have been 100%, 150% & 300% and 100%, 150% & 300% for tank 50% full and tank empty conditions in hard rock, medium soil and soft soil respectively. As per IS:1893-2002 (Part -2) draft code Provisions, base shear increased by 56%, 135% and 253% with zone changing from II to III, IV and V respectively in hard rock. The corresponding values are 56%, 135% and 253% and 54%, 131% & 246% respectively for medium and soft soil with tank full condition. The base shear values have been 60%, 140% & 260% and 54%, 131% & 246% for tank 50% full and tank empty conditions in hard rock, medium soil and soft soil respectively.

### 5.2.2 Effect of Seismic Zone on Base Moment

Figs. (5-7) show the variation of base moment with seismic zone and it can be observed that the base moment increased with increasing zone factor, which increases from zone II to V, for all soil types and also for different tank-fill conditions. For the circular tank considered, as per IS:1893-1984 Provisions, base shear increased by 100%, 150% and 300% as the zone changed from II to III, IV and V respectively in case of hard rock. The corresponding values are 100%, 150% & 300% and 100%, 150% & 300% respectively in medium and soft soil for tank full condition. On the other hand, the values have been 102%, 153% & 300% and 100%, 150% & 300% for tank 50% full and tank empty conditions in hard rock, medium soil and soft soil respectively. Similarly, as per IS:1893-2002 (Part -2) draft code Provisions, base moment increased by 58%, 137% and 256% with zone changing from II to III, IV and V respectively in hard rock. The corresponding values are 60%, 203% & 260% and 60%, 203% & 256% respectively for medium and soft soil with tank full condition. The base moment values have been 60%, 140% & 260% and 56%, 135% & 246% for tank 50% full and tank empty conditions in hard rock, medium soil and soft soil respectively.

### 5.2.3 Effect of Seismic Zone on Hydrodynamic Pressure

Figs.(8-15) present variation of hydrodynamic pressure on wall and base slab with seismic zone i.e. Zone factor. It could be observed that the hydrodynamic pressure, as per IS: 1893-1984, both on wall and base slab increased with increasing zone factor, which increases from zone II to V, for all types of soils and also for different tank-fill conditions. For the circular tank considered, hydrodynamic pressure on wall and base slab, as per IS:1893-1984 Provisions, increased by 56%, 135% and 253% as the zone changed from II to III, IV and V respectively in hard rock . The corresponding values are 56%, 135% & 253% and 56%, 135% & 253% respectively for medium soil and soft soil with tank full condition. The values are 60%, 140% & 260% and 54%, 131% & 246% for tank 50% full and tank empty conditions in hard rock, medium soil and soft soil respectively. As per IS: 1893-2002 (Part -2) draft code Provisions, hydrodynamic pressure on wall increased by

60% 140% and 184% as the zone changed from II to III, IV and V respectively in case of hard rock. The corresponding values are 60%, 151% & 244% and 54%, 131% & 260% respectively for medium soil and soft soil with tank full condition. On the other hand, the values have been 60%, 140% & 260%; 60%, 140% & 244%; and 54%, 131% & 278% for tank 50% full condition in hard rock, medium soil and soft soil respectively.

### 5.2.4 Effect of Soil Type on Base Shear

With reference to figs. (2 - 4), base shear in case of 1000 Cu.m circular tank, as per IS:1893-1984, increased by 100%,150% and 300% with the zone change from II to III , IV and V respectively in hard rock. The corresponding values are 100%, 150% & 300% and 100% &, 108%, & 147% respectively in medium and soft soil with tank full condition. On the other hand, the values have been 102%, 153% & 300% and 100%, 150%, & 300% for tank 50% full and tank empty conditions in hard rock, medium soil and soft soil respectively. According to draft code, the base shear increased by 56%, 135% & 253% on change of zone from II to III, IV and V respectively in case of hard rock in tank full condition. The corresponding increase in base shear have been 56%, 135% & 253% and 54%, 131% & 246% respectively for medium and soft soil with tank full conditions. On the other hand, the values have been 60%, 140% & 260% and 54%, 131% & 246% for tank 50% full and tank empty conditions in hard rock, medium soil and soft soil respectively.

### 5.2.5 Effect of Soil Type on Base Moment

With reference to figs.(5-7), the base moment in circular tank, as per IS:1893-1984, increased by 100%, 150% and 300% as the zone changed from II to III, IV and V respectively in case of hard rock. The corresponding values are 100%, 150% & 300%; and 100%, 108% & 147%; respectively in medium and soft soil with tank full condition. But, the provisions of draft code increased the base moment by 60%, 151% and 244% as the zone changed from II to III, IV and V respectively in case of hard rock. The corresponding values are 60%, 140% & 260%; and 54%, 148% & 265%; respectively for medium and soft soil with tank full condition. In the same way, the corresponding values have been 60%, 140% & 260%; 60%, 140% & 244%; and 54%, 131% & 278%; for tank 50% full condition in hard rock, medium soil and soft soil respectively.

### 5.2.6 Effect of Soil Type on Hydrodynamic Pressure

Figs. (8 - 15) depict the variation of hydrodynamic pressure on wall and base slab with seismic zone i.e. Zone factor. It could be noticed that the hydrodynamic pressure on wall, as per IS: 1893-1984, increases with increasing zone factor, which increases from seismic zone II to V, for all types of soils and also for different tank-fill conditions i.e. tank full condition, tank 50% full condition and tank empty condition. As per IS:1893-1984 provisions, hydrodynamic pressure on wall and base slab increased by 100%,146% and 300% as the zone changed from II to III , IV and V respectively in case of hard rock while the corresponding values are 100%, 150% & 300%; and 100%, 150% & 300%; respectively for medium soil and soft soil with tank full condition. The values have been 100%, 150% & 300%; and 100%, 150% & 300%; for tank 50% full and tank empty conditions in hard rock, medium soil and soft soil respectively. On adopting the draft code Provisions, hydrodynamic pressure on wall increased by 60%, 151% and 244% as the zone changed from II to III, IV and V respectively in case of hard rock in tank full condition. The corresponding increase in hydrodynamic pressure on wall have been 60%, 151% & 244% and 54%, 131% & 260% respectively for medium and soft soil with tank full condition. Similarly, the corresponding values are 60%, 140% & 260%; 60%, 140% & 244%; and 54%, 131% & 278%; for tank 50% full condition in hard rock, medium soil and soft soil respectively.

### 5.2.7 Analysis using SAP-2000

SAP-2000 is a 3D object based graphical modeling environment to the wide variety of analysis and design options completely integrated across one powerful user interface. The 1000 Cu.m circular overhead water tank was analyzed employing structural analysis programme (SAP-2000) software package also, apart from theoretical procedures using IS: 1893-1984 and draft code, for different zones (II-V) & Soil types (Hard rock, Medium soil, soft soil) and three different tank-fill conditions. The water tank modeling done using SAP-2000 is as shown in fig.1. The results of SAP-2000 analysis were found in agreement with those of the draft code.

## 6. CONCLUSION

The following Conclusions are drawn based on the analysis of circular water tank considered:

1. Base shear increases in the range of 54-300% with increase of seismic zone successively from Zone-II to V, for varying soil types in all tank filling conditions.
2. Base moment increases in the range of 58-300%, as the seismic zone changed Zone-II to V in succession, for varying soil types for all tank-fill conditions.
3. Hydrodynamic pressure on wall and base slab of tank also increases in the range of 56-260% with the successive increase in seismic zone from Zone-II to V, for different soil types and all tank fill conditions.
4. There is an increase in base shear by 30-430% for the tank analyzed with draft code as compared to the results of IS: 1893-1984, for the seismic zones, soil types and tank fill conditions considered in the study.
5. The increase in impulsive hydrodynamic pressure, with increasing zone factor, on wall & base slab is higher for tanks analyzed using draft code as compared to the results of IS: 1893-1984.

## REFERENCES

[1]. Gaikwad, M.V. (2013). “Comparison between static and dynamic analysis of elevated water tank”. International Journal of Civil Engineering and Technology, 4(3), 2043-2052.

[2]. Gaikwad, M.V.(2013).“Seismic performance of Circular Elevated Water Tank with Framed Staging”. International Journal of advanced research in Engineering and Technology, 4(4), 159-167.

[3]. Hirde, S., Bajare, A. and Hedaoo, M. (2011). “Seismic performance of elevated water tanks”. International Journal of Advanced Engineering Research and Studies, 1(1), 78-87.

[4]. IITK-GSDMA (2007). “Guidelines for seismic design of liquid storage tanks”, National Information Centre for Earthquake Engineering, IIT Kanpur.

[5]. IS:1893-1984.“Criteria for Earthquake Resistant Design of Structures”, Bureau of Indian Standards, New Delhi.

[6]. IS:1893(Part-1)-2002. “Criteria for Earthquake Resistant Design of Structures”, Bureau of Indian Standards, New Delhi.

[7]. IS:1893(Part-2)-2002.“Criteria for Earthquake Resistant Design of Structures Part 2 Liquid Retaining Tanks”, Bureau of Indian Standards, New Delhi.

[8]. IS: 11682 -1985.“Criteria for Design Of Rcc Staging For Overhead Water Tanks”, Bureau of Indian Standards, New Delhi.

[9]. Jaiswal, O.R., Jain, S.K. (2005). “Modified proposed provisions for a seismic design of liquid storage tanks: Part I – codal provisions”. Journal of Structural Engineering, 32(3), 195-206.

[10]. Jaiswal, O.R, and Jain, S.K. (2005). “Modified proposed provisions for a seismic design of liquid storage tanks: Part II – commentary and examples”. Journal of Structural Engineering, 32(4), 297-310.

[11]. Jain, S.K., and Sajjad, S.U. (1993). “A Review of requirements in Indian codes for a seismic design of Elevated water tanks”. The Bridge and structural Engineering, 12(1), 1-15.

[12]. Ekbote, S.P. (2013). “Seismic behaviour of RC elevated water tank under different types of staging pattern”. Journal of Engineering, Computers & Applied Sciences, 2(8), 23-29.

[13]. Vamsidhar, S. (2007). “Analysis of water Tanks in accordance with IS:1893-2002(Part-II) Draft code”. Indian Concrete Institute Journal, 7(4), 21-26.